AD-A168 076 PREDICTION OF THE METABOLIC COST OF EXERCISE FROM MEASUREMENTS DURING RECOVERY(U) ARMY RESEARCH INST OF ENVIRONMENTAL MEDICINE NATICK MA MAR 86 1/1

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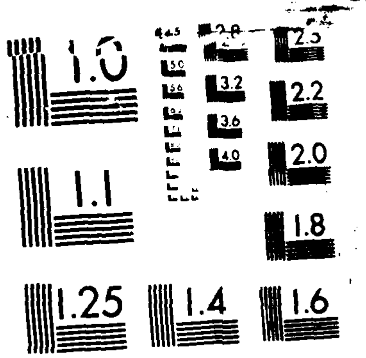

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1. REPORT NUMBER M24/86	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Prediction of the Metabolic Cost of Exercise from Measurements During Recovery		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Stephen J. Legg, Ph.D. Dr. James A. Vogel MAJ Joseph Dziados Tammy J. Doherty Mr. Robert Mello		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Research Institute of Environmental Medicine, Natick, MA 01760-5007		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Same as 9 above.		12. REPORT DATE March 1986 13. NUMBER OF PAGES 14 pages
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLAS 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18 SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Oxygen uptake,prediction, Exercise, Heart rate, Metabolic cost obstacle course

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study was designed to determine if post exercise recovery measurements could be used to predict the oxygen uptake (VO_2), minute ventilation (V_E) and heart rate (HR) during exercise. VO_2, V_E and HR were measured in 11 healthy males during the last minute of treadmill running (at various exercise intensities ranging from light to maximal effort) and for each 15 second period during three minutes of standing recovery.
For each variable measured, a least squares regression line was calculated from data collected during the interval between 15 and 60 seconds after cessation of

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exercise. The ability of the Y intercept of this line, denoted B_o, to predict the observed last-minute exercise value, denoted Y_o, was enhanced by one of two distinct methods. For VO_2 and HR, a linear least squares regression between Y_o and B_o was used to calculate correction co-efficients. The linear regression co-efficients of $(B_o - Y_o)$ versus the slope (B_1) of the original regression line enhanced the prediction of the observed exercise level of V_E. The following prediction equations were derived from these methods:

$$VO_2 = 1.108 + .804\,(B_o) \qquad (SEE = 0.290)$$
$$V_E = B_o + 30.47 + 11.14\,(B_1) \qquad (SEE = 12.13)$$
$$HR = 61.5 + .616\,(B_o) \qquad (SEE = 10.09)$$

In a separate validation experiment using 6 different males, the mean predicted values for VO_2, V_E and HR differed from observed last minute exercise values by $-0.08\ 1\ min^{-1}$, $1.0\ 1\ min^{-1}$ and 2.2 beats min^{-1} respectively. It is concluded that the equations described in this study, utilizing data collected during the first minute of recovery from exercise, may be useful in estimating the metabolic cost of exercise in situations where it is impossible to make direct measurements.

HUMAN RESEARCH

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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MARCH 1986

PREDICTION OF THE METABOLIC COST OF EXERCISE FROM MEASUREMENTS DURING RECOVERY

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ABSTRACT

This study was designed to determine if post exercise recovery measurements could be used to predict the oxygen uptake (VO_2), minute ventilation ($\dot{V}_E$) and heart rate (HR) during exercise. VO_2, $\dot{V}_E$ and HR were measured in 11 healthy males during the last minute of treadmill running (at various exercise intensities ranging from light to maximal effort) and for each 15 second period during three minutes of standing recovery.

For each variable measured, a least squares regression line was calculated from data collected during the interval between 15 and 60 seconds after cessation of exercise. The ability of the Y intercept of this line, denoted B_o, to predict the observed last-minute exercise value, denoted Y_o, was enhanced by one of two distinct methods. For VO_2 and HR, a linear least squares regression between Y_o and B_o was used to calculate correction co-efficients. The linear regression co-efficients of $(B_o - Y_o)$ versus the slope (B_1) of the original regression line enhanced the prediction of the observed exercise level of V_E. The following prediction equations were derived from these methods:

$$VO_2 = 1.108 + .804\,(B_o) \qquad (SEE = 0.290)$$

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$$HR = 61.5 + .616\,(B_o) \qquad (SEE = 10.09)$$

In a separate validation experiment using 6 different males, the mean predicted values for VO_2, $\dot{V}_E$ and HR differed from observed last minute exercise values by $-0.08\ l\ min^{-1}$, $1.0\ l\ min$ and $2.2\ beats\ min^{-1}$ respectively. It is concluded that the equations described in this study, utilising data collected during the first minute of recovery from exercise, may be useful in estimating the metabolic cost of exercise in situations where it is impossible to make direct measurements.

1. INTRODUCTION

The measurement of energy expenditure or oxygen uptake (VO_2) during vigorous exercise in the field has always presented a challenge to exercise physiologists. Traditionally, the Douglas bag (DB) has been used to collect timed amounts of expired air which is subsequently analysed for O_2 and CO_2 content and volume. However, the DB is large and cumbersome.

The development of small man-portable ventilation or oxygen consumption meters such as the Kofranyi-Michaelis (KM) meter (Muller and Franz 1952) and more recently the oxylog (Humphrey and Wolff 1977), have made field VO_2 measurements more convenient. However, there are still instances when the use of a man-portable device is unacceptable, both to the subject and the investigator. The bulkiness of these devices is a drawback when work is performed in restricted spaces. When the activity is extremely vigorous and demands high ventilatory rates, the respiratory resistance of the breathing valve may itself limit the performance of the task.

In cases where no direct measurement of VO_2 is possible, many investigators have measured heart rate using telemetry or small robust man-portable tape recorders, and have estimated VO_2 from pre-established subject-specific relationships between VO_2 and heart rate (HR). However, recent evidence (Burger 1969, McArdle et al 1981) suggests that this technque is poor at estimating the VO_2 of realistic tasks and that pre-established HR/VO_2 relationships should be (at the very least) task-specific. Even then, there are additional uncertainties, such as the effects of temporal lapse or changes in motivation, hydration, and training state of subjects.

The object of this study was to measure the VO_2 of soldiers who were instructed to give "an all-out effort" during the negotiation of an obstacle course. The course consisted of numerous obstacles which required soldiers to climb, jump, crawl, run, etc. DB's and portable oxygen consumption meters were clearly too bulky, heavy, or delicate to be considered and would have limited the performance of the soldiers due to high respiratory resistance at the high ventilatory rates expected during course traverse. Because of the variegated nature of the activities involving considerable static muscular effort while negotiating the course, we felt that the heart rate may not give a reliable estimate of the VO_2, even if we were able to pre-determine any task and subject-specific HR/VO_2

relationships. Indeed, it was difficult to choose a "representative" task for which the HR/VO_2 relationship should be determined.

We therefore, concluded that an alternative approach might be to estimate the VO_2 for course traverse from recovery VO_2 measurements. To our knowledge, this approach has not previously been described. Thus, our purpose here is to describe the laboratory studies which were conducted and the statistical procedures utilised in an attempt to determine if post exercise recovery measurements could be used to estimate exercise VO_2. In addition, the same approach was used to estimate exercise minute ventilation (V_E) and HR.

2. METHODS

2.1 Subjects

Eleven healthy males gave their fully informed consent and volunteered to participate in the experiment. Their age, height and weight were measured, as were their skinfold thickness at 4 sites (biceps, triceps, subscapular and suprailiac) on their right side using Harpenden calipers. Body fat content was calculated using the equations of Siri (1961) and Durnin and Womersley (1974). Percentage body fat was determined as the ratio of body fat conent to body weight. Lean body mass was determined as the difference between body weight and fat weight. Peak oxygen uptake (VO_2 peak) was determined according to the method described in 2.2. The highest VO_2 determined during the last minute of maximal effort exercise was recorded as VO_2 peak.

2.2 Experimental Design

Each subject ran on a motor driven treadmill for 3 minutes at 4 to 6 different exercise intensities ranging from light to maximal effort (approximately 50% to 100% VO_2 peak). During the last minute and a half of exercise, and throughout 3 minutes of recovery, the subject wore a noseclip and breathed through a low-resistance Koegel Y-shaped breathing valve. His minute ventilation (V_E) and oxygen consumption (VO_2) were measured using an automated computerised on-line technique (Cote et al 1978) over 4 consecutive 15-second intervals during the last minute of exercise, and also over 12 consecutive 15-second intervals during

recovery, when the subject stood upright and as motionless as possible. A continuous electrocardiogram was recorded and the heart rate determined for the same 15 second intervals during exercise and recovery. A total of 54 runs were performed.

The on-line metabolic measurement system utilised a Hewlett-Packard 9820 desk-top calculator to compute parameters from signals averaged over a 15 second sample period. An infra-red CO_2 analyser (Beckman LB-2) and a fuel cell O_2 analyser (Applied electrochemistry S-3A) were used to measure expired gas concentrations, and a Fleish pnumotachograph utilised for air flow measurements. A variable volume gas mixing chamber was employed to avoid breath-by-breath variations in gas concentrations. VO_2 was calculated according to standard equations (Consolazio 1963) and expressed in 1 min^{-1} corrected to standard temperature and pressure of dry gas (STPD). V_E was also expressed in 1 min^{-1}, but corrected to body temperature and pressure of saturated gas (BTPS).

Earlier studies had demonstrated that there were no statistically significant differences between the on-line system and the conventional DB method for measuring VO_2 (Cote et al 1978) over the range of values obtained in the present experiment. In addition, immediately prior to the present study, the on-line and DB methods were compared. Again, there were no statistically significant differences in VO_2 or V_E. The correlation co-efficient for the 2 methods was 0.98.

3. RESULTS

3.1 Exercise and recovery cardiorespiratory data

The mean (SD) physical characteristics of the subjects were age 31.3 (5.4) years, height 173.9 (7.5) cm, weight 72.0 (9.3) kg, body fat 13.4 (4.5)%, lean body mass 62.2 (6.7) kg, VO_2 peak 3.88 (0.55) 1.min^{-1} and 54.3 (8.1) ml kg^{-1} min^{-1}. The mean (SD) data for all runs (n=54) on all subjects (n=11) for VO_2, V_E and HR for the last minute of exercise and during 3 minutes of recovery, are given in Table 1. The mid-point of each 15-second interval was selected to represent discrete measurement time. For ease of explanation, the recovery data points were numbered 1 to 12 where point number 1 corresponds to recovery time 7.5s.

3.2 Derivation of equations for the estimate of last-minute exercise values of VO_2, V_E and HR from recovery data

The objective of this analysis was to develop a method for predicting last-minute exercise values of VO_2, V_E and HR from recovery data. The letter Y is used to represent VO_2, V_E and HR since the same procedures were used on all 3 variables. The method adopted to derive the most appropriate prediction equations is outlined below:

Step 1

Physiological data were obtained as described in 2.2.

Step 2

The four (15 sec) measurements made over the last minute of exercise were averaged, and denoted Y_o corresponding to recovery time zero.

Step 3

Linear and exponential least squares regressions were performed over lengths of recovery data from one minute to 3 minutes, both including and excluding the first recovery data point. These regression equations take the form:

$$\text{linear:} \qquad Y = B_o + B_1 \text{ (Time)}$$

$$\text{exponential:} \qquad Y = B_o \left(e^{B1(\text{Time})}\right)$$

The Y intercepts (B_o) of these regression curves were used as initial predictors of Y_o:

$$Y_o' = B_o$$

Table 2 shows the standard error of the estimate (SEE) associated with each group of data points for both the linear and exponential fits.

Step 4

It was clear that all values of SEE in Table 2 were too high for this simple regression method to have any practical applications. The next step was to develop correction co-efficients to reduce the SEE. The first and most logical approach was to perform a linear regression between Y_o and B_o for each regression type (linear or exponential) over each data set:

$$Y_o = C_o + C_1 (B_o)$$

For each test, the original values of B_o were adjusted using the regression co-efficients C_o and C_1 to calculate a better prediction of Y_o

$$Y_o'' = C_o + C_1 (B_o)$$

The standard errors associated with each adjusted prediction (Y_o'') are shown in Table 3.

Step 5

A second correction method relies on the linear relationship of the difference ($B_o - Y_o$), and the slope (B_1) of the original regression:

$$(B_o - Y_o) = C_o + C_1 (B_1)$$

An adjusted prediction of Y_o was calculated from the original regression co-efficients, B_o and B_1, and the correction co-efficients, C_o and C_1,

$$Y_o''' = B_o - C_o - C_1 (B_1)$$

The SEE associated with each set of recovery points for this method is given in Table 4.

Step 6

To decide which method would be best for predicting VO_2, V_E and HR from recovery data we examined the tables of SEE values. The standard error of the estimate was

consistently higher for the predictions based on exponential regressions, and in data sets of more than 5 data points. Original, uncorrected Y_0 predictions (Y_0') were less accurate than either of the corresponding adjusted predictions. Since for field application it is impractical or impossible to measure HR or collect expired air over the first 15 seconds of recovery, only those methods that exclude the first recovery data point were considered. The adjusted linear methods using points 2 through 4 gave good predictions of Y_0 for VO_2 and V_E. The linear method, adjusted by the process described in Step 4, over points 2 through 6, gave the best prediction for HR. In practice it may be inconvenient to collect HR for 30 seconds longer than V_E and VO_2 data, and the prediction of HR from points 2 through 4 was only slightly inferior to using points 2 through 6 (SEE = 10.09 vs 9.90 respectively - Table 3).

Step 7

We threfore concluded that the most simple and practical method of predicting VO_2, V_E and HR from recovery data is to use the following equations for data obtained for points 2 through 4 (15-30, 30-45 and 45-60 seconds following the cessation of exercise):

$$VO_2 = 1.108 + 0.804\,(B_0) \qquad (SEE = 0.290)$$

$$V_E = B_0 + 30.47 + 11.14\,(B_1) \qquad (SEE = 12.13)$$

$$HR = 61.65 + 0.616\,(B_0) \qquad (SEE = 10.09)$$

where B_0 and B_1 are the Y intercept and slope, respectively, of the linear regression equations relating VO_2, V_E and HR to the mid-points of the timed data collection periods (22.5, 37.5 and 52.5 seconds respectively).

3.3 Validation

A separate experiment was undertaken in order to validate the prediction method described in 3.2 (Step 7). Six healthy male subjects were studied. Their mean (SD) physical characteristics were, age 33.7 (8.8) years, height 172.5 (5.2) cm, weight 80.3 (15.5) kg, body fat 16.0 (6.9)%, lean body mass 66.6 (7.2) kg, VO_2 peak 4.20 (0.52) l min^{-1} and 53.3 (8.6) ml kg^{-1} min^{-1}.

Each subject participated in 4-6 exercise bouts, running on an inclined treadmill. The exercise intensities ranged between 50% and 100% VO_2 peak. Since the prediction technique was being developed for field use, Douglas Bags were used instead of the on-line system. HRs were measured, and the expired air collected during the last minute of exercise and at the 3 appropriate 15-second intervals during recovery. VO_2, V_E and HR were calculated as described in 2.2.

The actual (observed) last minute exercise values for VO_2, V_E and HR were then compared with the values predicted using the method described in 3.2 (Step 7). In a total of 17 comparisons, the mean predicted values for VO_2 and V_E and HR differed from mean observed values by -0.08 l min^{-1}, 1.0 l min^{-1} and 2.2 beats min^{-1} respectively (Table 5). These differences were not statistically significant, and the respective standard errors of differences were 0.06, 5.1 and 1.4.

4. DISCUSSION

This study has demonstrated that the VO_2, V_E and HR of healthy fit young males during the last minute of treadmill running, can be predicted from recovery measurements with good accuracy using linear prediction equations. The data obtained in this study indicated an accuracy of $\mp$ 0.3 l min^{-1}, $\mp$ 12 l min^{-1}, and $\mp$ 10 beats min^{-1} for VO_2, V_E and HR respectively. The validity of the method has been demonstrated for a small group of healthy males running on treadmill. The mean percentage differences between observed and predicted VO_2, V_E and HR were -2.2, +1.0 and +1.4% respectively.

Most of our subjects were experienced in running on treadmills and breathing into Douglas bags. We have not yet assessed the validity of the method for naive subjects. In practical usage, we feel that it would be prudent to familiarise subjects with breathing through mouthpieces and valves, and in the appropriate control of body posture during the one minute post-exercise period of recovery measurements.

Our analysis included maximal and submaximal data together. We examined the possibility of obtaining materially different equations for these 2 categories separately, but failed to find any material differences. Thus, for our data, there was no justification for deriving separate prediction equations for maximal

and submaximal exercise. Furthermore, we examined the relationship between exercise intensity and prediction ability and found that there was minimal advantage in deriving separate prediction equations.

The prediction method has not been "field" tested. Indeed, it is difficult to see how an adequate field test could be conducted since the method itself was designed to overcome our inability to measure VO_2 and V_E during vigorous exercise involving a maximal effort traverse of an obstacle course. Furthermore, in the laboratory experiments, the subjects attained a steady state during the last minute of treadmill running before the recovery measurements were made. In the field, even if subjects take 3-5 minutes to negotiate an obstacle course, it is possible, though unlikely, that they may not attain a steady state condition on account of the changing exercise intensity associated with the negotiation of the various obstacles. Thus it is possible that the VO_2, V_E and HR may still be changing upon cessation of exercise and application of the prediction method outlined in 3.2 (Step 7) may under or over-estimate the metabolic cost of obstacle course traverse.

In conclusion, the method described in the present paper, utilising data collected during the first minute of recovery from exercise, may be useful in estimating VO_2 in situations where it is impossible to make these measurements directly.

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TABLE 1. Mean (SD) data obtained for the last minute of exercise and during successive 15-second intervals during 3 minutes of recovery.

		$\dot{V}O_2$ ($l\ min^{-1}$)		$\dot{V}_E$ ($l\ min^{-1}$)		HR (beat min^{-1})	
		mean	SD	mean	SD	mean	SD
Last minute of exercise		3.15	0.74	98.0	39.3	163.8	36.8
Recovery time (sec)	Data Point (see text)						
0-15	1	2.43	0.69	74.1	33.1	156.1	36.7
15-30	2	1.99	0.60	62.1	32.7	141.3	38.1
30-45	3	1.58	0.40	53.6	29.0	126.8	38.2
45-60	4	1.25	0.31	47.0	25.9	115.9	36.2
60-75	5	1.02	0.28	41.1	23.3	109.0	35.0
75-90	6	0.86	0.28	35.9	21.0	103.8	32.5
90-105	7	0.77	0.24	31.9	16.6	101.3	30.5
105-120	8	0.72	0.25	30.3	15.7	99.3	28.6
120-135	9	0.66	0.22	27.9	14.5	96.8	27.4
135-150	10	0.63	0.21	26.7	13.9	96.9	26.1
150-165	11	0.61	0.18	25.3	12.1	95.9	25.5
165-180	12	0.59	0.19	25.0	12.9	94.6	24.6

TABLE 2. Standard Error of the Estimate (SEE) values associated with the simple regression technique described in section 3.2 (step 3).

Data points	Simple Linear VO_2	Simple Linear V_E	Simple Linear HR	Simple Exponential VO_2	Simple Exponential V_E	Simple Exponential HR
1 to 3	.594	23.61	8.28	.536	22.53	10.67
1 to 4	.609	24.12	7.77	.493	22.39	10.02
1 to 5	.660	25.20	8.16	.489	22.67	10.31
1 to 6	.732	26.45	9.26	.530	23.36	11.28
1 to 7	.817	27.73	11.04	.610	24.16	12.52
1 to 8	.909	29.54	13.21	.725	26.14	14.25
1 to 9	.990	31.19	15.43	.808	27.60	16.43
1 to 10	1.071	32.93	17.87	.919	29.62	18.94
1 to 11	1.147	34.61	20.13	1.025	31.57	21.31
1 to 12	1.218	36.32	22.16	1.124	33.64	23.46
2 to 4	.707	28.48	14.91	.593	26.24	18.18
2 to 5	.798	29.53	16.25	.571	25.76	18.80
2 to 6	.904	30.97	18.28	.620	26.54	20.81
2 to 7	1.016	32.34	20.60	.728	27.52	21.78
2 to 8	1.130	34.42	22.96	.879	29.78	23.18
2 to 9	1.221	36.24	25.14	.973	31.48	25.16
2 to 10	1.310	38.14	27.60	1.104	33.70	27.59
2 to 11	1.390	39.91	29.76	1.221	35.80	29.83
2 to 12	1.463	41.69	31.61	1.325	37.96	31.77

TABLE 3. Standard Error of the Estimate (SEE) values associated with the corrected prediction described in section 3.2 (step 4).

	Simple Linear Adjusted by Step 4			Simple Exponential Adjusted by Step 4		
Data points	VO_2	V_E	HR	VO_2	V_E	HR
1 to 3	.267	12.81	5.68	.278	13.40	7.03
1 to 4	.240	11.26	5.82	.235	11.72	6.64
1 to 5	.239	11.00	6.65	.232	11.04	7.62
1 to 6	.252	11.17	6.95	.267	11.47	7.97
1 to 7	.267	11.45	7.33	.292	11.88	8.25
1 to 8	.283	11.97	7.66	.333	12.64	8.40
1 to 9	.285	12.26	8.00	.312	12.87	8.68
1 to 10	.295	12.62	8.35	.322	13.33	8.98
1 to 11	.305	13.05	8.75	.341	14.13	9.38
1 to 12	.316	13.27	8.98	.355	14.36	9.62
2 to 4	.290	12.81	10.09	.306	14.70	11.28
2 to 5	.323	12.62	10.21	.351	13.59	11.36
2 to 6	.347	13.11	9.90	.398	14.31	11.07
2 to 7	.366	13.61	9.92	.423	14.84	10.70
2 to 8	.383	14.20	9.94	.464	15.47	10.34
2 to 9	.380	14.57	10.04	.421	15.74	10.32
2 to 10	.391	14.92	10.21	.430	16.11	10.40
2 to 11	.400	15.33	10.49	.443	16.80	10.66
2 to 12	.410	15.46	10.60	.449	16.79	10.80

TABLE 4. Standard Error of the Estimate (SEE) values associated with the corrected prediction described in section 3.2 (step 5).

	Simple Linear Adjusted by Step 5			Simple Exponential Adjusted by Step 5		
Data points	VO_2	V_E	HR	VO_2	V_E	HR
1 to 3	.252	12.32	5.30	.272	11.68	5.78
1 to 4	.241	11.44	6.26	.253	10.96	6.90
1 to 5	.241	11.17	7.86	.250	10.81	9.07
1 to 6	.251	11.24	9.16	.270	11.38	11.07
1 to 7	.263	11.38	10.25	.290	11.87	12.42
1 to 8	.278	11.86	11.09	.328	12.65	13.26
1 to 9	.276	12.09	11.72	.313	12.86	14.21
1 to 10	.281	12.39	12.20	.328	13.24	14.96
1 to 11	.290	12.87	12.52	.347	14.06	15.45
1 to 12	.300	13.09	12.69	.366	14.35	15.82
2 to 4	.297	12.13	13.35	.348	12.63	15.68
2 to 5	.325	12.41	14.15	.359	12.71	17.42
2 to 6	.347	13.04	14.62	.381	14.16	18.97
2 to 7	.366	13.61	14.90	.401	15.31	18.96
2 to 8	.384	14.20	14.97	.429	15.78	18.69
2 to 9	.378	14.56	14.95	.410	16.09	18.61
2 to 10	.387	14.89	14.85	.429	16.28	18.34
2 to 11	.395	15.33	14.68	.443	16.93	18.03
2 to 12	.404	15.47	14.55	.454	16.80	17.76

TABLE 5. Comparions of mean (SD) observed ($\bar{Y}o$) and predicted ($\bar{Y}o'$) data (n=17) The predictions are based on the equations given in section 3.2 (step)

	VO_2 ($l\ min^{-1}$)	V_E ($l\ min^{-1}$)	HR (beats min^{-1})
$\bar{Y}o$	3.65	101.5	158.8
$\bar{Y}o'$	3.57	102.5	161.0
Mean Difference ($\bar{Y}o'$ - $\bar{Y}o$)	-0.08	1.0	2.2
Mean % Difference ($\bar{Y}o'$ - $\bar{Y}o$)/$\bar{Y}o$ x 100	-2.2	1.0	1.4
SD of the Difference	0.24	20.9	5.4
SE of the Difference	0.06	5.1	1.4
r	0.97	0.85	0.93
t	1.40	0.19	1.67

END

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